# RFID Tags Enabled by Flip Chip


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### Abstract

*We think of flip chip as a solution for better performance, high I/O or absolute size reduction. But a new and exciting technology is now emerging where the flip chip is the unique answer to extreme cost reduction in a very low I/O product, the RFID tag.*

*RFIDs are **R**adio **F**requency **Id**entification systems - tiny two-way radios with immense commercial potential. The simplest design consists of an antenna mated to an IC using only two connection points. Power and query signals are sent as electromagnetic radiation. The energized chip returns information as a digital radio signal. RFID offers elegant solutions to old problems like finding things and counting them.*

*2-way RF in a miniature very low cost form factor is relatively new. The 2-way RF query-response system, with on-chip data processing capability, is a new product category. The simplest RFID tag is a smart bar code product that does not require line-of-sight access. The "look through" feature brings unequaled efficiency and flexibility to warehouse management, inventory control and related areas where items must be located, identified and tallied. Much more sophisticated products are planned, however.*

*Broad success for RFID products requires extremely low cost and ultra-high volume manufacturing. Minimal circuit cost is achieved, not with traditional copper conductors on FR4, but with Polymer Thick Film (PTF) conductive ink on thin plastic film substrate. The adhesively bonded flip chip is the ideal means of interconnecting to the PTF circuit.*



Keywords: conductive adhesives, flip chip, polymer thick film, PTF, RFID, underfill.


## Introduction

Most of you have never heard of Polymer Thick Film although it has been used for decades as the world's most cost-effective and successful fully additive, waste-free circuitry and assembly technology [1]. Computer keyboards and mouse pads, hand calculators, telephones and other consumer products use PTF circuitry. Conductive adhesives, the joining materials of the PTF family, are used in most flat panel displays, business telephones, medical sensors, printers and, more recently in high density memory modules using Flip Chips.

The PTF process differs significantly from the traditional subtractive copper etching method. In fact, PTF is nearly the opposite of etching - conductors are applied exactly, and only, where needed. PTF is a true *printed* circuit concept. Conductive ink is efficiently screen-printed onto a bare dielectric and then quickly hardened. Since no water or chemicals are used, just about any dielectric, even paper, can be used as the substrate. However, thin polyester film is very popular and widely available at a cost of pennies per square foot.

While the PTF process was actually developed during WW II for the artillery fuze [2], [3], the most popular commercial use has been in the consumer area where the low cost feature overwhelmed other circuit technologies. The membrane switch used for various keyboards is a good example. Note that these electronic assemblies are produced with no copper and no solder using a gentle process that permits low cost, but temperature-sensitive materials to be used. Let's look closely at the solderless assembly process.

The solderless assembly process uses metal-filled conductive adhesives as a substitute for solder paste. The adhesive can be applied by printing, stenciling and other methods used for solder paste. The big difference is that adhesive is hardened by polymerizing its resin binder instead of reflowing at high temperatures like solder. Adhesive assembly has proved so reliable and cost-effective that around 1 billion adhesive joints have been produced during the 1990's.

Adhesives can also be used to assemble bare die in the form of flip chips and this is now done commercially. During the 1990's, flip chip moved to 2$^{nd}$ generation technology replacing ceramics with low cost organic substrates like FR4 and BT. Yet very little has been done on ultra-low cost materials like polyester film. Conductive adhesives are well suited for fine pitch SMT, like flip chips and their low temperature processing (120$^{o}$ to 140$^{o}$C) permits inexpensive plastic films to be used. Let's look more closely at the all important flip chip adhesives since several types can be used for flip chip.

**Isotropic Conductive Adhesives**

ICA are highly loaded, up to 80% or more by weight, with silver powder and flake. Conductive particles make intimate contact with one another so that conductivity is approximately equal in the X, Y and Z directions, hence the name isotropic. The most common systems use liquid epoxy resins and hardeners to create solventless pastes that can be printed, stenciled, needle dispensed or pin transferred. Hardening can take place as low as room temperature, but 140$^{o}$C is more typical for optimum properties. It is the low temperature processing and wide compatibility that makes the isotropics the assembly choice for PTF circuits on plastic film.

Junction stability under temperature and humidity aging has been a concern for adhesives. Although the adhesive is stable, oxide formation on some component and circuit surfaces can cause unacceptable increases in junction resistance when oxide layers form between the adhesive interface and the component or circuit finish. Solder, used to bump most flip chips, has produced unstable joints with adhesives. This problem was solved with special junction-stable adhesives that can penetrate through oxides. Poly-Solder, the most commonly used adhesive for SMT assembly, solves the problem by penetrating the oxide layer with conductive particles. This type of adhesive can pass 1000 hours under 85% rh/85$^{o}$C conditions using FCs with eutectic tin-lead solder interfaces [4].

**Anisotropic Conductive Adhesives**

ACAs contain a much lower loading of conductive particles. They are formulated to behave as insulators in the X-Y plane since particles do not touch to form conductive pathways. But when sandwiched between pairs of opposing conductors, the isolated conductive particles complete the electrical path in the Z-plane. Typical conductive particles are solid metal balls or metal-plated elastomeric microspheres that can provide "spring action" to compensate for thermal expansion of the binder during thermocycling. The assembly step requires simultaneous application of heat and pressure using custom equipment. It is important to note that these adhesives have built-in selectivity. Only opposing conductor pairs are connected in the Z-plane and no shorting results in the X-Y plane. This means that the anisotropic adhesives can be applied over the entire bonding area, not just the circuit bonding pads. It is the auto-selectivity that makes the anisotropics so appealing for fine pitch applications. An added benefit is that no flip chip underfill is required since the ACA covers the volume between the chip and substrate. The conductive path is a pressure contact.

**Putting It All Together**

PTF circuit processing, although limited to the line resolution densities of screen printing, is totally adequate for producing RFID circuits. The most common circuits are not much more than antennas with mounting pads for FCs. Densities of 5 mil lines and spaces have been achieved on high speed printing lines at Poly-Flex Circuits and this satisfies RFID requirements. The high volume capacity of screen printers, both sheet-fed and continuous roll, can produce several hundred thousand circuits per hour depending on their size. The PTF process using 2 or 3 mil thick polyester film is considered to be the lowest cost process for manufacturing this type of circuit. We still have not fully determined if normal process variation will introduce antenna resonance problems for the ultrahigh frequency systems that operate at several gigahertz.

**Flip Chip Assembly**

A greater challenge is that of assembly since very high production rates (> 5,000 chips/hour) will be needed to keep costs in the target range. The ICA and ACA types of adhesives described earlier can both be used but each has different advantages and limitations [5]. There is also the important issue of chip protection. Is underfill required or can encapsulant be applied over the chip? Does the built-in underfill feature of the ACA offer a net advantage even though assembly may be slower?

Let's begin with the more common isotropic, or ICA material. These materials are pastes that can be stenciled down to feature sizes 3 mils (75 microns) and even finer if the required stencil can be made. The adhesive can be applied to hundreds of bond sights on a circuit sheet or reel section in a matter of seconds. FCs can then placed on the "wet" adhesive using newly developed high-speed flip chip shooters. Exposing the assembly to $120^o$ to $140^oC$ for a few minutes thermally hardens the adhesive.

One alternate method, now used commercially in Japan and the US, is to simply dip the bumped flip chip into a thin reservoir of conductive adhesive paste. A thin layer adhesive is spread out on a flat surface using a doctor blade. The chip is dipped into the adhesive, with bumps down, and then withdrawn. Properly formulated adhesive will cling to the bumps. The chip can now be placed on the circuit pads and thermally hardened. The adhesive dipping process is actually a simple modification of the rotating drum fluxing process. Adhesive is substituted for liquid flux on the rotating drum dispensers available on most flip chip bonders. While the dip process is a resourceful approach for avoiding precision adhesive dispensing, it can limit assembly rates and may not be the best method for high volume RFIDs.

Once a satisfactory adhesive assembly process is selected, there is one more step required to produce a robust and reliable RFID tag. The FC must be protected and the relatively fragile adhesive bond must be mechanically enhanced. Both goals are accomplished with underfill, a form of dielectric adhesive used to raise the reliability level of FCs on organic substrate. The key issue is one of production rate. A successful RFID tag line will need to produce at 5,000 to 10,000 assemblies per hour and the underfill process could significantly hinder the productivity. However, a UV-cured underfill could come close to matching the production demands. Fortunately, polyester film will transmit enough UV to permit curing an underfill.

Another practical alternative is to deposit encapsulant over the assembled flip chip. Application from above instead of underfilling invariably allows air to become trapped under the chip. However, reliability appears adequate probably because of the small chips used (often 1 mm or less). The encapsulant appears to put the conductive adhesive joints under compression as indicated by a decrease in junction resistance after encapsulation. Stencil-printed ICA and encapsulant-over-die appears to be a suitable approach to manufacturing RFID tags.

Anisotropic type adhesives can also be used with the advantage of eliminating the underfill step. A typical RFID tag manufacturing process could entail applying ACA film to the circuit or chip followed by thermal bonding. Most of today's ACAs require a minimum of several seconds of bonding time since the adhesive must melt, deform and cure if it is a thermoset. A high production rate would only allow for about 1/2 of bonding time. Work is underway to develop ACAs that can meet the very fast bonding time in a process that is compatible with temperature-sensitive polyester. Although the goal has remained elusive for many years, it should still be possible to apply liquid ACA, place the chip and harden the adhesive in an oven. The challenge is to get good junctions without applying external force.

**The RFID Products**

Smart Cards are certainly a worthwhile target for flip chip RFID technology. The expected paradigm shift from the old "plug in" contact cards to contactless is expected to boost this new approach. The traditional contact type Smart Cards use wire bonding that is incompatible with PTF and is less suitable for high frequency RF. The contactless RF-type, based around flip chip, can be totally sealed and even be made flexible. While the very large worldwide smart card market may be important, it is a small potential market for RFID compared to those that are emerging.

The RFID owes it versatility to its non-contact, wireless attribute. Reading/writing from a distance enables markets not possible with the contact cards. The more obvious markets are inventory, warehousing, transfer control and other automated cataloging. RFID tags can be applied to boxes, machinery, grocery items, luggage and even people to permit location and identification on the fly with automatic tallying. Radio frequency ICs now exist that can be energized and queried from distances of several meters. The antenna can serve as both the inductive energy and signal link so that no batteries are used. Tags can be bonded to items allowing an RF reader to send energy and a query signal. The tag then responds with a uniquely coded RF signal that is recorded by the reader.

The transmit-receive concept is being applied to a long list of applications that include automated fuel purchase, warehouse control, medical IDs, easy pass toll cards, etc. Even more consumer-oriented applications are forecast in the near future such as automatic food and consumer product check out. The RFID would allow bulk scanning of items instead of the one-at-a-time bar code method in use today. RFID technology goes well beyond bar code, however. The tags can be queried, perform logic functions and written to just like a smart card. Still on the drawing board but quite feasible are tracking and locating products that would use satellite systems like Iridium. Cargo and shipments could be tracked across the country and even around the world.

Here's one final thought. Could the RF two-way linking principle be used to produce ultra-high density packages? After all, doesn't the RFID tag qualify as a package even now? It is a packaged IC that is readily connected to a system. Forget wires, joints and leads. The chip-to-board interconnect is RF energy and depending on the bandwidth, the I/O equivalent could be very high. Wireless packaging? And why not!

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